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PROBLEMS
IN
THERMODYNAMICS
AND
HEAT ENGINEERING

MILLER — BERRY — RILEY

PROBLEMS
IN
THERMODYNAMICS
AND
HEAT ENGINEERING

BY

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PREFACE.

The problems in this book are used in connection with courses of instruction in Heat Engineering at the Massachusetts Institute of Technology. With the exception of a few questions taken from examinations set by other institutions, these problems have been outlined by the authors to meet the needs of students in the various departments of engineering.

The pages are perforated at the inner edge and space is left between successive problems so that they can be cut out and pasted on the sheets on which the solutions are to be made. Numerical answers are given at the back of the book.

E. F. M.
C. W. B.
J. C. R.

Massachusetts Institute of Technology,
August, 1911.

PROBLEMS IN THERMODYNAMICS AND HEAT ENGINEERING.

THE LAWS OF THERMODYNAMICS AND DEFINITIONS OF EFFICIENCY.

1. How many B.t.u. would be required per H.P. hour by an engine working with an efficiency of 100 per cent?

2. A heat engine requires 19,500 B.t.u. per brake H.P. hour. What is its efficiency for transforming heat into work?

3. What is the efficiency of the Carnot cycle between temperatures of 1100° and 212° F.?

4. A steam engine requires 13,860 B.t.u. per I.H.P. hour. The temperature of the boiler steam is 350° F. and of the condenser, 120°. What is the ratio of the efficiency to that of the Carnot cycle for the same limits?

5. What do you understand by the " thermal efficiency " of a heat engine?

6. The temperature range in a Carnot cycle is 500° F. The heat transformed into work is 41.2 per cent of that wasted. What are the temperatures at which heat is supplied and rejected?

7. A power plant uses 1.75 lbs. of coal per K.W. hour. The heat of combustion of the coal is 14,000 B.t.u. per lb. What is the efficiency of the plant for converting heat into electric energy?

8. A test of a cross-compound engine with direct connected generator gave the following:

Temperature of steam at throttle	348.5° F.
Temperature in exhaust pipe	167.5° F.
Heat absorbed in boiler per lb. of steam	1045 B.t.u.
Weight of steam per I.H.P. hour	18.5 lbs.
Indicated H.P.	256
Output of generator	133 K.W.

What fractional part of the heat supplied was utilized in the cylinders? What per cent of the Carnot efficiency was realized by the unit? What per cent of the indicated power was delivered at the switchboard?

9. An oil engine is reported to use only .39 lb. of fuel per K.W. hour output of the dynamo it drives. Combustion of the oil yields 19,000 B.t.u. per lb. 19 per cent of the indicated power is lost between the cylinder and the terminals. Suppose it is known that the maximum temperature cannot reach 2800° F. and that the exhaust temperature is 900° F. Show whether the economy reported is credible.

10. During compression, 45,000 ft. lbs. of work are done upon a fluid and 10 B.t.u. are taken from it by conduction What change takes place in its internal energy?

11. A Carnot engine receives heat at 340.5° F. and rejects heat at 140.5° F. The work done per cycle is 550 ft. lbs. What is the maximum change in entropy during the cycle?

12. In the Carnot cycle between 500° and 50° F., 700,000 ft. lbs. of work are done. Find the heat supplied and the maximum change in entropy.

13. In a Carnot cycle the temperature range is 450°. Thirty B.t.u. are supplied at 1500° F. Find the efficiency, work done, and heat rejected per cycle, and the maximum change of entropy.

14. A Carnot engine works between the temperatures of 440.5° and 240.5° F. and between the entropies .023 and .035. How much energy is represented by the indicator diagram?

15. An engine working on the Carnot cycle between 400° and 150° F. uses 1 lb. of gas. The maximum change in entropy is .2 of one unit. Find the efficiency, the heat received, the heat rejected, and the work done per cycle.

16. 969.7 B.t.u. are required to vaporize a pound of water at atmospheric pressure. The volume of the water is 0.016 cu. ft. and that of the dry steam 26.8 cu. ft. Find the increase in internal energy and in entropy during the process.

17. The specific heat of air at constant pressure, C_p, is 0.2375 B.t.u. Find the change in entropy when 3 lbs. of air are heated at constant pressure from 70° to 1000° F.

18. A ton of water is heated from 70° to 358° F. Find the approximate increase in internal energy, assuming the variations in volume and specific heat to be negligible. Has the entropy decreased or increased and how much?

19. One hundred lbs. of air enclosed in a steel reservoir are cooled by radiation from 200° to 40° F. How much heat is lost and what is the change of entropy? For air, $C_v = .169$ B.t.u. per lb.

20. Considering the specific heat of water as unity, find the approximate change of entropy when 2 lbs. of water at 425° F. are mixed with 5 lbs. at 70° F.

21. The temperature of a boiler furnace is 2500° F. and that of the feed water 70° F. What is the efficiency of the Carnot cycle between these limits? If the total heat of combustion were absorbed in the boiler, where the steam temperature is 358.5° F., what per cent of it could then be transformed into work by the Carnot cycle, the lowest available temperature being 70°? Explain fully this loss in theoretical efficiency.

22. In the manufacture of lead pipes the solid lead is forced through an annular die by pressure. If the pressure necessary be 20,000 lbs. per sq. in., how much will the temperature of the metal rise in passing through the die? Lead weighs 710 lbs. per cu. ft. Its specific heat is .0314.

THERMODYNAMICS OF GASES.

40. What weight of air at 200.3 lbs. gage and 140.5° F. is contained in a cylinder 6 ft. diameter and 20 ft. long?

41. A receiver holds 15 lbs. of oxygen at 18° C. and under 200 lbs. gage pressure. What weight will it hold at 90° F. and under the barometric pressure of 30.3 ins.?

42. If a pound of air is to be compressed into a volume of 2 cu. ft. at 60° F., what must be the final pressure in inches of mercury?

43. Compressed air is to be stored in tanks 8 ins. in diameter and 12 ft. long. The maximum pressure at 130° F. must not exceed 1500 lbs. gage. What weight of air can be stored in each tank? What would be its volume before compression if the barometer read 29.6 ins. and the thermometer 40° F.?

44. Two tanks each of 3 cu. ft. capacity, and of equal weight when empty, are filled, one with oxygen and the other with hydrogen, at 1500 lbs. gage pressure. The temperature of each is 70° F. What is the difference in weight? What would be the volume of each gas at freezing point and atmospheric pressure?

45. Oxygen and hydrogen are to be stored separately in receivers. The two gases unite in burning in the proportion of 1 lb. of hydrogen to 8 lbs. of oxygen. What should be the cubic contents of the receivers if 20 lbs. of hydrogen and 160 lbs. of oxygen are to be stored at 500 lbs. gage and at 100° F.?

46. A receiver containing air at atmospheric pressure has its contents exhausted until the gage shows 29.9 ins. vacuum. The barometer reads 30.6 ins. What per cent by weight of the air has been removed?

47. How many pounds of air at 214.3 lbs. gage pressure and at a temperature of 110.5° F. can be compressed into a receiver 2 ft. in diameter and 10 ft. long?

48. The airship Zeppelin II had an external covering enclosing 16 balloonettes with a total maximum capacity of 500,000 cu. ft. The space between the balloonettes and the envelope was filled with air at atmospheric pressure and temperature. The weights were as follows:

Engines	1,100 lbs.
Gasoline for 60 hours	13,200 "
Crew of 15 men	2,250 "
Frame, covering, shafting, ballast, etc.	15,000 "

460,000 cu. ft. of hydrogen were put in at 70° F., when the barometer read 30.2 ins.

Find the pull on the anchor ropes.

On releasing the ropes, the balloon rose till it floated in equilibrium at a height where the temperature was 40° F. Assuming that no gas had been lost, and that the temperature in the balloonettes was the same as that of the surrounding air, find the barometer reading at that level.

49. A balloon of 35,000 cu. ft. maximum capacity, weighing with car, occupants, ballast, etc., 2320 lbs., has 32,372 cu. ft. of hydrogen run into it at 60° F., the barometer reading 30.5 ins. The volume of air displaced by everything except the hydrogen is negligible.

The balloon rises and floats in equilibrium at a level where the temperature is 10° below zero F. If 10 per cent of the hydrogen has been lost by leakage and the mean temperature of the remaining gas is 32°, find the barometer reading at this level and the difference in pressure per sq. in. inside and outside the balloon. Find the pull on the anchor rope before the ascension.

50. Fifty cu. ft. of air at 90° F. are under a pressure of 2500 lbs. absolute per sq. in. Are the intrinsic energy and the entropy greater or less, and by how much, than if the air were at 15 lbs. absolute and 60° F.?

51. A cu. ft. of air at 491.5° F. exerts 14.7 lbs. gage pressure per sq. in. How much do its internal energy and its entropy exceed those of the same air under standard conditions?

52. A lb. of air under pressure of 150 lbs. absolute per sq. in. occupies 3 cu. ft. What is its temperature? How much does its internal energy exceed that of air under standard conditions?

53. Three lbs. of air expand at a constant gage pressure of 184.3 lbs. until the volume has increased from 3 to 5 cu. ft. Find the work done, the heat added, and the increase in entropy.

54. A closed cylinder of 20 cu. ft. capacity contains 2 lbs. of air at 20.3 lbs. gage. Heat is added till the pressure is 40.3 lbs. Find the initial and final temperatures and the increase in internal energy and in entropy.

55. Five lbs. of hydrogen at 200 lbs. absolute per sq. in. and 100° F. expand at constant pressure till the volume is doubled. Heat is then added at constant volume till the pressure becomes 300 lbs. absolute. Find the total heat added and the final temperature.

56. Find the increase in entropy of 2 lbs. of a perfect gas during isothermal expansion at 140.5° F. from an initial pressure of 84.3 lbs. gage and a volume of 20 cu. ft. to a final volume of 40 cu. ft.

57. Three cu. ft. of air expand from 300 to 100 lbs. absolute per sq. in. without change in temperature. Find the work done, the change in internal energy, and the heat added during expansion.

58. Three lbs. of a perfect gas expand at a constant temperature of 100° F. from an initial pressure of 134.3 lbs. gage, and a volume of 30 cu. ft. to a final volume of 60 cu. ft. Find change in entropy and the heat added during expansion.

59. Two hundred lbs. of air at 147 lbs. absolute per sq. in. expand at 100° F. till the volume is doubled. Find the work done and the heat added.

60. Two hundred lbs. of air at 147 lbs. absolute per sq. in. and 100° F. expand adiabatically until the volume is doubled. Find the work done and the final temperature.

61. How much work must be done to compress 1000 cu. ft. of free air from 14.5 to 145 lbs. absolute per sq. in. without change in temperature? How much heat must be removed during the compression?

62. Air from a room at 80° F. is compressed isothermally to 100 lbs. gage and then expanded at constant pressure to .4 of its original volume. If the barometer reads 29 ins. and the air is dry, find the net quantity of heat received or rejected by the air and the net work done upon it.

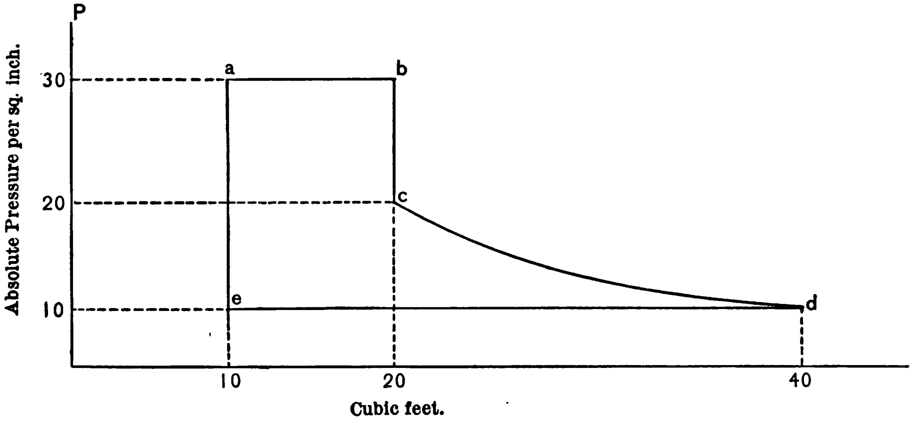
63. Twenty lbs. of air are heated at a constant pressure of 200 lbs. absolute per sq. in. until the volume increases from 20 cu. ft. to 40 cu. ft. Find the initial and final temperatures, the change in internal energy, and the increase in entropy. How much heat is added?

64. Five lbs. of air undergo frictionless adiabatic expansion from a temperature of 70° F. until the volume is doubled. Find the work performed.

65. In the case of a perfect gas evaluate the definite integral $\frac{dQ}{T}$ for a reversible change between any two states defined by v_1T_1 and v_2T_2. dQ is the heat received per lb. of gas at absolute temperature T.

If the relation between pressure and volume is given by the equation pv^n = constant, show that the total heat received is proportional to $T_2 - T_1$ and find the complete expression for it.

66. The *PV* projection of a closed cycle worked through by a perfect gas is as shown below. *cd* represents an isothermal expansion. T_A = 800° F. absolute. Find the heat added or rejected during each operation and the work done per cycle.



67. Three cu. ft. of air at 100 lbs. gage expand to 9 cu. ft. without change of internal energy. Find the heat added and the external work done. If the final temperature is 240° F., what is the increase in entropy?

68. Two cu. ft. of air expand adiabatically and without friction from an initial pressure of 85.3 lbs. gage until the volume is doubled. Find the external work done.

69. Find the changes in entropy and internal energy of 3 lbs. of a perfect gas which are heated without change of density from a pressure of 5.3 lbs. gage and a volume of 20 cu. ft. until the absolute pressure is doubled, and which are then permitted to expand isothermally until the initial pressure is reëstablished. The final temperature is 540.5° F.

70. Air is compressed in a water-jacketed cylinder from atmospheric pressure to 100 lbs. gage pressure, its volume being reduced from 13 cu. ft. to 2.56 cu. ft. The barometer reads 30.2 ins. How much work is required per cu. ft. of air of the initial condition?

71. Three lbs. of air undergo frictionless adiabatic expansion from a temperature of 600° F. to a temperature of 200° F. Find external work performed during the expansion.

72. Gas initially occupying 1 cu. ft. at 200 lbs. absolute per sq. in. expands in a cylinder until when its volume becomes 4 cu. ft. its pressure is 40 lbs. absolute. Write an approximate equation expressing in simplest form the pressure at any point of the expansion in terms of the corresponding volume.

73. Two thousand cu. ft. of air at 240 lbs. absolute pressure on the sq. in. expand at a constant temperature of 420° F. to a pressure of 15 lbs. absolute. How much work is done by the expansion? How much heat must be added? How much does the entropy increase while heat is being added?

74. If this same 2000 cu. ft. of air at 240 lbs. absolute on sq. in. and at 420° F. had expanded adiabatically how many foot pounds of work would have been done? What would the change in internal energy amount to? What would be the final temperature?

75. Six lbs. of air expand at a constant pressure of 450 lbs. absolute per sq. in. until the volume has increased from 2.5 to 4 cu. ft. Find the work done, the heat added, and the increase in entropy.

76. Draw to scale the *PV*, the *TV*, and the *PT* projections of the diagram shown in problem 66, using *P*, *T*, and *P*, respectively, as ordinates.

Draw to a scale of 1 in. = 200° absolute.
1 in. = 5 cu. ft.
1 in. = 5 lbs.

77. Draw the $T\ \phi$ diagram of the diagram shown in problem 66.

78. A tank holds 75 cu. ft. of air at 300 lbs. absolute per sq. in. It is cooled till the pressure drops to 250 lbs. absolute, at which time the temperature is 68° F. How much heat was removed? Find the decrease in entropy.

79. A thousand cu. ft. of illuminating gas ($k = 1.4$) are confined under a constant gage pressure of 0.5 lb. Find the heat absorbed by the gas and the increase in its entropy if the temperature changes from 40° to 70° F.

80. Ten cu. ft. of gas are admitted to a cylinder at a constant pressure of 100 lbs. absolute per sq. in. Show that the work it does during admission is $n - 1$ times the work it could perform if subsequently permitted to expand indefinitely according to the law pv^n = constant. Interpret this relationship for adiabatic and isothermal expansions.

81. Compressed air is forced into a pipe line at 250 lbs. gage pressure and 150° F. At the further end of the line it has lost 30 lbs. in pressure and cooled to 70° F. What is the loss of intrinsic energy per pound of air? If the pipe is the same size at each end, is the final velocity greater or less than the initial? By what per cent?

82. The expansion of air in an air motor followed the law $pv^{1 \cdot 3}$ = constant. During the expansion the temperature dropped 100° F. How much heat was received from or given to the cylinder walls per pound of air?

83. In an air compressor the compression line is represented by the equation $pv^{1 \cdot 35}$ = constant. The temperature of the air is raised 200° F. How much heat is lost to the cylinder walls per pound of air?

84. An unknown mixture of gases, for which the ratio of the specific heats is 1.4, changes from a condition p_1 = 15 lbs. per sq. in., T_1 = 70° F., and v_1 = 10 cu. ft., to a condition p_2 = 10 lbs. per sq. in. and t_2 = 200° F. Find the changes in volume, internal energy, and entropy.

85. A cylinder 20 ins. in diameter, with one end open to the atmosphere, is fitted with a piston that requires a total force of 50 lbs. to overcome its friction. It contains 5 cu. ft. of air at 12 lbs. absolute and at 60° F. The barometer reads 30 ins. How much work is required to move the piston outward a distance of 2 ft. if no heat enters or leaves the cylinder?

86. Find the exponent for an equation to show the relation between p and v of air compressed in a cylinder to $\frac{1}{5}$ of its original volume, and rising in pressure from 13 to 68 lbs. absolute per sq. in. If the initial volume is 4 cu. ft. and the temperature 100° F., find the work done, the heat received or abstracted, and the gain or loss in intrinsic energy.

87. A cylinder of 10 ins. diameter has a piston with a 2-in. rod passing through a stuffing box into the atmosphere. Each end of the cylinder contains 3.5 cu. ft. of air at 20 lbs. gage pressure and at 60° F. The barometer reads 30.5 ins. The force necessary to move the piston against friction is 40 lbs. How much work must be done to move the piston 22 ins. towards the crank end, if the temperature remains the same in each end? What is the maximum pull on the piston rod?

88. Solve problem 87, assuming adiabatic instead of isothermal changes.

89. Suppose a cylinder of nonconducting material to be supplied with a frictionless nonconducting piston. Ten lbs. of air are stored in one end of the cylinder in 1 cu. ft. space under a pressure of 1500 lbs. absolute per sq. in. In the other end there are 5 lbs., occupying 2 cu. ft under a pressure of 500 lbs. per sq. in. If the piston be permitted to move, what will be the pressure and temperature in the two ends when the piston finally comes to rest?

90. Air expands from a pressure of 100 lbs. absolute per sq. in. to a pressure of 50 lbs. absolute per sq. in. according to the equation $pv^{1.3}$ = a constant. If the initial temperature is 500° F., find the final temperature, and calculate the heat supplied during expansion, if the volume of the air before expansion is 1 cu. ft.

91. Five and one-half lbs. of air are heated at a constant pressure of 150 lbs. absolute per sq. in. until the volume increases from 5 cu. ft. to 12 cu. ft. Find the initial and final temperatures, the change in internal energy, and the increase in entropy; also the heat added.

92. Four cu. ft. of air at 60 lbs. gage expand isodynamically to 12 cu. ft. Find the heat added and the external work done. If the final temperature is 200° F., what is the increase in entropy?

93. Suppose a hot-air engine, in which the maximum pressure is 200 lbs. absolute per sq. in. and the maximum temperature 800° F., to work on the Carnot cycle. Let the initial volume be 2 cu. ft., the volume after isothermal expansion 6 cu. ft., and after adiabatic expansion 10 cu. ft Find the external work done per cycle. If the engine is double-acting and makes 40 revolutions per minute, what is its I. H. P.?

SATURATED AND SUPERHEATED VAPORS. USE OF STEAM AND ENTROPY TABLES AND PLOTS.

130. Water at 100° F. is fed to a boiler in which the pressure is 180 lbs. absolute per sq. in. How much heat must be supplied to evaporate each pound?

131. How much heat will be required to convert 20 lbs. of feed water at 100° F. into steam at 150.3 lbs. gage, containing 3 per cent moisture?

132. What is the volume occupied by this 20 lbs. of mixture?

133. How much is the intrinsic energy increased above that of the 20 lbs. of water at 100° F.?

134. Twenty lbs. of hot water at 200° F. are mixed with 30 lbs. at 100° F. and with 100 lbs. at 50° F. What is the final temperature of the mixture?

135. Three lbs. of a mixture of steam and water at 165 lbs. absolute have a volume of 2 cu. ft. How much heat will be needed to increase this volume to 7.5 cu. ft. at the same pressure?

136. A small boiler contains 20 lbs. of water and 5 lbs. of steam, both at a temperature of 327° F. What is the pressure and what is the volume of the boiler?

137. Water at 180° F. is fed to a boiler in which the pressure is 120 lbs. gage. How much heat must be supplied to evaporate each pound? Find work developed during expansion. What is the change in entropy?

138. One lb. of wet steam at 160 lbs. absolute occupies 2.5 cu. ft. What per cent of moisture is present? What is the "quality" of the steam?

139. One lb. of water at 298° F. is evaporated into steam, 98 per cent dry, at 65 lbs. pressure. What is the increase in volume? By how many foot pounds is the intrinsic energy increased? What is the increase in entropy?

140. What is the entropy of 1 lb. of mixture of water and steam at 150 lbs. absolute pressure, the mixture being 26 parts steam by weight?

141. How much does the entropy of 3 lbs. of mixture 80 per cent steam at 260 lbs. absolute exceed that of 3 lbs. of water at 212° F.?

142. Find the intrinsic energy, total heat, entropy, and volume of 5 lbs. of a mixture of water and steam which is 80 per cent steam, the pressure being 140 lbs. absolute.

143. Three lbs. of water are heated from 60° F. and evaporated under 125.3 lbs. gage pressure. Find the heat added and the changes in volume, internal energy, and entropy.

144. Two lbs. of steam at 343° F. and 108 lbs. gage pressure occupy 6 cu. ft. Find its intrinsic energy and its entropy above 32° F.

145. Two pipes deliver water into a third. One supplies 300 gals. per minute at 40° F., the other 80 gals. per minute at 200° F. What is the temperature of the water after the two streams unite?

146. Ten gals. of water per minute are to be heated from 55° to 212° F. by passing through a coil surrounded by steam at 120 lbs. gage pressure. How much steam is required per minute?

147. Ten gals. of water per minute at 212° F. are to be obtained by blowing dry steam at 25 lbs. gage pressure into water at 55° F. What is the minimum quantity of steam required per minute?

148. Three pipes discharge water into the same main, one supplying 150 gals. per minute at 180° F., the second 270 gals. per minute at 45°, and the third, 12 gals. per minute at 210°. Without allowing for variation in the specific heat or in density, solve for the final temperature in the main. Solve again, allowing for all variations.

149. Steam at 3 lbs. gage pressure with 8 per cent priming is blown into an open tank containing water at 40° F. The initial and final weights of water are 300 and 306.5 lbs. Assuming no loss by evaporation or radiation, what is the final temperature?

150. Steam at 20 lbs. gage pressure with 1 per cent priming is blown into a tank containing 200 lbs. of water at 50° F. The final weight is 212 lbs. and the final temperature 112° F. Assuming no loss of water by evaporation, how much heat has been lost by absorption and radiation?

151. A closed tank of 12 cu. ft. capacity contains 5 lbs. of water and water vapor at 70° F. If no air is present, what is the absolute pressure and what proportion of the contents is in the form of vapor?

152. A closed tank containing 10 lbs. of steam at 150 lbs. absolute pressure with 2 per cent priming is cooled until 95 per cent of the contents is in the liquid form. How much heat is removed? What is the final temperature and the final pressure?

153. Two lbs. of hot water at 800° absolute expand, without addition or loss of heat from or to any outside source, to 600° absolute. How much steam by weight is there at the end of the expansion?

154. A thousand lbs. of water per minute are to be heated from 65° to 150° F. by passing through a coil surrounded with steam at 50 lbs. gage pressure. If the steam supplied has 6 per cent priming, how many pounds are required per minute?

155. Three hundred lbs. of steam per hour are condensed in the jackets of a steam engine. If the jacket supply is at 130 lbs. gage with 4 per cent priming, and the radiation to the air is 35 thermal units per minute, how much heat per hour is supplied by the jackets to steam in the cylinder?

156. Circulating water pumped to a cooling tower loses 5 per cent of its weight by evaporation and is thereby cooled to 85° F. If the loss is made up by water at 33° F. fed continuously into the suction pipe, what will be the temperature on entering the condenser?

157. Two lbs. of steam initially dry expand adiabatically from 130 to 20 lbs. absolute pressure per sq. in. Find the initial and final volumes and the work performed.

158. A cu. ft. of steam having a pressure of 100 lbs. absolute and 15 per cent priming expands adiabatically till the temperature becomes 310° F. Find the final volume and the change in internal energy.

159. A horizontal, multitubular boiler 60 ins. diameter and 16 ft. long, with 84 three-inch tubes, has its water level 1 ft. 8 ins. from the top. The steam gage shows a pressure of 120 lbs. If the boiler should explode, how much energy would be liberated by the steam? How much by the water? Explain whatever you assume concerning the final condition of the boiler's contents.

160. Ten lbs. of steam and water are contained in a closed receiver of 29 cu. ft. capacity at a temperature of 254° F. Heat is applied until the pressure reaches 125 lbs. gage. How many B.t.u. are required?

161. By means of the Steam Tables, show that when the steam outlets of a boiler are closed and the pressure is rising, the gain in intrinsic energy per pound of dry vapor is less than the work done upon it by the rising pressure.

162. How many foot pounds of work are done by an adiabatic expansion of 30 lbs. of dry steam from 409° F. and the corresponding pressure 273.3 lbs. absolute to 265° F. where the pressure corresponding is 38.53 lbs. absolute? What is the volume occupied by the steam after expansion?

163. The specific volumes of a liquid and its vapor at a given temperature are σ and s, and the specific heats are c and h, respectively. Show that if T be the temperature, and p the corresponding saturation pressure, then

$$\frac{1}{778}(s-\sigma)\frac{dp}{dT} = c - h + \frac{dr}{dT} = \frac{r}{T}\,.$$

164. A mixture of liquid and vapor (dryness fraction $= x$) undergoes an adiabatic decrease of temperature. Show that this is accompanied by condensation or evaporation according as

$c\,(1-x) + xh$ is positive or negative.

165. A mixture, half water and half steam, at 150° F., in a nonconducting cylinder, is compressed reversibly. Show that evaporation takes place as compression increases. Examine what happens to the mixture if its initial temperature is 340° F.

166. Four hundred lbs. of water at 60° F., 800 lbs. of water at 80° F., and 10 lbs. of steam at 15.3 lbs. gage with 10 per cent moisture are brought together in a tank. What is the temperature of the mixture?

167. A digester has a capacity of 190 cu. ft. Seventy-five lbs. of steam primed 2 per cent are run into it. The temperature of the steam entering the digester is 351° F. How much steam was condensed in it?

168. Seven and four-tenths cu. ft. of steam are taken into a nonconducting cylinder at 126 lbs. absolute and 368° F., are expanded to atmospheric pressure, and exhausted. Find the work developed during the operation, assuming no friction loss.

169. What is the volume of 5 lbs. of steam at 129.3 lbs. gage pressure and at 359.3° F.?

170. At 129.3 lbs. gage pressure 2 lbs. of steam occupy 7 cu. ft. Find its condition and its intrinsic energy above that of water at 32° F.

171. A cubic foot of steam at 144 lbs. absolute weighs .30 lbs. What is its quality?

172. Two lbs. of steam and water at 129.3 lbs. pressure above the atmosphere occupy 6 cu. ft. Heat is added and the pressure kept constant till the volume is 8.5 cu. ft. Find the final condition, the external work done in expanding, the heat added, and the change in entropy.

173. Three lbs. of steam and water occupying 7 cu. ft. under a pressure of 100 lbs. absolute per sq. in. expand at constant temperature until the volume is 10 cu. ft. Find the heat added and the work done.

174. One lb. of steam having a dryness fraction of 0.96 expands adiabatically from an initial pressure of 126 lbs. absolute per sq. in. to a final pressure of 40 lbs. absolute per sq. in. Find from the tables the dryness fraction at the end of expansion, the change of internal energy, and the external work done. Compare the value of the external work thus obtained with that obtained on the assumption that the steam expands according to the law pv^n = constant, where $n = 1.131$.

175. How much heat must be added to 500 lbs. of water at 80° F. to make same into steam at 100 lbs. absolute pressure on sq. in., the steam being primed 4 per cent? What is the volume occupied by this 500 lbs.? How much has the intrinsic energy been increased?

176. Water is heated by steam which is blown directly into it from a pipe when the pressure is 90.3 lbs. gage, the steam being dry. Ten thousand lbs. of water are to be heated from 40° to 195° F. How many pounds of steam are needed for this?

177. Ten lbs. of steam at 150.3 lbs. gage with 2 per cent of moisture are condensed at constant pressure in the jackets of an engine. The condensed steam is trapped out at the temperature of the steam. How much heat is given up?

178. Steam at 100.3 lbs. gage at a temperature of 500° F. is used to heat water in an open heater from 40° to 210°. How much water will a pound of steam heat?

179. Two lbs. of steam at 150 lbs. absolute on sq. in. occupying a volume of 4 cu. ft. are expanded at a constant pressure by the addition of heat till the volume is 8 cu. ft. How much heat must be added?

180. Two lbs. of steam at 110.3 lbs. gage and 380° F. expand adiabatically to atmospheric pressure. What are the initial and final volumes and the change in internal energy?

181. Five lbs. of steam at 130 lbs. absolute pressure and 480° F. expand isodynamically to 120 lbs. absolute pressure. Find the heat added and the change in entropy.

182. Four lbs. of saturated steam with 2 per cent priming expand without change in intrinsic energy from an initial pressure of 250 lbs. absolute to a final temperature of 290° F. Find the work performed and the increase in entropy and volume.

183. Saturated steam at 150 lbs. gage, containing 2 per cent of water passes through a superheater on its way to an engine. Its final temperature is 400° F. Find the increase in volume and internal energy, and the heat added per pound.

184. Steam at 3 lbs. gage pressure, superheated 60°, is condensed in a radiator and finally trapped out at 150° F. How much heat is given up by each pound of steam?

185. A cylinder 24 ins. in diameter, open at the top, has a tight-fitting piston weighing 904.8 lbs. The piston may be assumed to move without friction. On top of this piston there is a helical spring which compresses 1 in. per 4524 lbs. load. Each inch which the piston lifts then adds 4524 lbs. to the load on the piston. There are 400 lbs. of water at 100° F. under the piston between the piston and the closed end of the cylinder. How much heat must be added to make this piston rise 20 ins.? What is the final pressure? What is the per cent steam? What is the increase in entropy?

186. Calculate the work obtainable from 1 cu. ft. of dry, saturated steam initially at a pressure of 200 lbs. per sq. in. absolute, when expanded adiabatically to 5 cu. ft. Find the dryness at the end of expansion. State the final pressure.

THE FLOW OF FLUIDS.

220. Explain the meaning and derivation of the following equation for the velocity of a jet of either gas or steam flowing through a nozzle:

$$V_2 = [2\,g\,(E_1 - E_2 + p_1v_1 - p_2v_2) + V_1^2]^{\frac{1}{2}}.$$

Give the full denomination of each symbol used.

221. Transform the above expression to a working formula for obtaining the velocity of wet steam. Explain the denomination of all symbols and tell what data and what assumptions are required for obtaining a numerical solution.

222. What weight of steam will escape into the atmosphere per hour through a ½-in. cylindrical opening in a receiver in which the pressure is 80 lbs. gage?

223. Steam initially dry, saturated, and at rest, at a pressure of 120 lbs. absolute per sq. in., flows through a nozzle into the atmosphere, at the rate of 1 lb. per second. What should be the area of the cross section of the nozzle at a point where the pressure is 40 lbs. absolute per sq. in., and what should be the approximate area at the throat?

224. Show that for any gas or vapor flowing through a nozzle from an initial pressure of p_1, past a section where the pressure is p_2, the increase in kinetic energy of the jet is represented by $\int v\,dp$, no matter what heat interchanges there are between the fluid and the nozzle.

225. The equations $W = \text{const.} \times A\,\frac{p_1}{\sqrt{T_1}}$ and $W = \text{const.} \times A\left[\frac{p_2\,(p_1 - p_2)}{T_1}\right]^{\frac{1}{2}}$ give the weight of gas discharged through an orifice for which A represents the area. Name the conditions under which each should be used. Explain fully the physical necessity for both of these equations.

226. A steam meter has an annular orifice with outside and inside diameters of 1 in. and ⅞ in. The pressure maintained on one side is 100 lbs. gage; on the other, 75. About how much saturated steam will pass through per hour?

227. Steam initially at 130 lbs. gage and superheated 100° drops 60 lbs. in passing through a 1-in. circular orifice. Find the weight of steam passing per hour.

228. Steam containing 2 per cent moisture at 100 lbs. gage pressure escapes into the atmosphere through a cylindrical orifice with rounded approach. If the expansion can be considered adiabatic and frictionless, what is the velocity of the issuing jet?

229. Explain generally the principles on which are based the equations for adiabatic frictionless flow of fluid, viz.:

$$\frac{V_2^2}{2g} - \frac{V_1^2}{2g} = E_1 + p_1v_1 - (E_2 + p_2v_2) = \int_2^1 v\,dp.$$

Derive the practical form of the first equation as applied to the flow of steam.

230. The kinetic energy of a jet of steam at the outlet of a nozzle, per pound of steam discharged, is $778\,(H_1 - H_2) + .016\,(p_1 - p_2)$, provided the velocity of approach is negligible. When H represents the total heat above that of water at 32°, and p the absolute pressure per square foot, the result is in foot pounds. Show that the same expression applies whether the steam at entrance be wet or superheated. Does this expression assume that no heat is lost through the nozzle walls? Does it assume no increase in entropy due to friction?

231. Find the maximum weight of air which can be delivered per minute through a properly designed nozzle having a minimum diameter of 2 ins., if the initial and final pressures are 100 and 80 lbs. gage, respectively, and the initial temperature is 100° F.:

(*a*) If the flow is frictionless and adiabatic.
(*b*) Using Fliegner's empirical formula.

232. Steam initially at 150 lbs. gage pressure and 450° F. leaves a DeLaval turbine nozzle at 1 lb. pressure above atmospheric. Assuming 10 per cent loss in friction, what is the velocity of the issuing jet? What is the quality of steam issuing?

233. Steam in a nozzle, expanding adiabatically from an initial pressure of 125 lbs. absolute per sq. in., is not to contain any moisture at the point where its pressure is 25 lbs. absolute. What is the minimum superheat required initially? Assume that the kinetic energy of the jet at the point in question is 5 per cent less than if there were no friction.

234. Steam in a nozzle, expanding adiabatically from an initial pressure of 125 lbs. absolute per sq. in., is not to contain any moisture at the point where its pressure is 20 lbs. absolute. What is the minimum for the initial temperature in degrees Fahrenheit? Assume that at the point in question the kinetic energy of the jet is 5 per cent less than if there were no friction.

235. During an engine test the following observations were taken with a throttling calorimeter: Gage pressure in steam pipe, 120.0 lbs.; gage pressure in calorimeter, 15.0 lbs.; temperature in calorimeter, 260° F.; barometer, 29.92 ins. Find the per cent of priming in the steam.

236. What is the maximum priming in steam of 150 lbs. gage pressure which can be measured by a throttling calorimeter discharging to the atmosphere, provided at least 10° superheating are desired?

237. In problem 235 how much will the result be in error if the thermometer is in error 5 degrees? If the thermometer is correct but the calorimeter gage is in error 1 lb.?

238. Steam at 150 lbs. gage pressure enters a throttling calorimeter where it expands to 18 lbs. gage. Its temperature is then 265° F. The throttling orifice is $\frac{1}{4}$ inch diameter. If the calorimeter discharges to the atmosphere, how much steam escapes per hour?

239. Steam at 30 lbs. gage pressure, known to contain about 5 per cent priming, is to have its quality accurately determined by a throttling calorimeter. The barometer reads 30.2 ins. An exhaust pipe leading to a condenser with 24-in. vacuum is available to receive steam from the calorimeter. Under these conditions can the desired information be obtained?

240. Steam at 58 lbs. absolute pressure per sq. in. is known to contain between 3 and 4 per cent of moisture. Will it be possible to determine its quality with a throttling calorimeter if the calorimeter discharges to the atmosphere?

241. A De Laval turbine of 350-H.P. rated capacity has seven nozzles. The steam at the entrance is under a pressure of 169.0 lbs. absolute and is superheated 57.5°. The exit pressure is 1 lb. absolute. The loss through friction in the nozzle amounts to 15 per cent. It may be assumed that 70 per cent of the kinetic energy of the jet is utilized. Find the steam per H.P. per hour, velocities at throat and at exit, and diameters. Assume taper 1 in 10 and sketch nozzle. (The taper of a cone should be expressed in terms of the diameters, not the radii.)

242. In the preceding problem on design of a De Laval nozzle the exit velocity was found to be 3780 ft. per sec. If the nozzle makes an angle of 20° with the plane of the wheel, and the exit angle of the blade is 20°, and if there is no exit velocity of whirl, what is the entrance angle? What is the velocity of the blade, and what per cent of energy of the jet is utilized? What is the end thrust per pound of steam passing per second?

243. Suppose that in problem 242 there is no axial thrust. What is the entrance angle? What is the exit angle? What is the velocity of blades? What per cent of the energy of the jet is utilized?

244. A 300-H.P. De Laval turbine with 5 nozzles is supplied with steam at 187.7 lbs. absolute, superheated 141° F. The back pressure is 1 lb. absolute. Assuming the nozzle friction to be 15 per cent and that only 70 per cent of the kinetic energy of the issuing jet is utilized in the blades, find the dimensions of each nozzle.

245. Discuss the fundamental principles involved in turbines of the Curtis and of the Parsons types. Point out the differences in mechanical construction made necessary by these fundamental differences.

246. If V is the velocity with which steam issues from the nozzles of an impulse turbine, a is the angle between the direction of the nozzles and the circumferential path of the vanes, and c the circumferential velocity of the vanes, show that the efficiency of a turbine designed for no end thrust is a maximum, neglecting frictional losses, when

$$c = \frac{V}{2} \cos a.$$

247. Deduce an expression for the velocity of an adiabatic flow of steam through an orifice.

248. Describe fully the principle of the throttling calorimeter. Illustrate by means of the $T\phi$ diagram, (*a*) the history of the steam changes and (*b*) the range of applicability. Deduce the equation for the quality of the steam.

249. In designing a nozzle to give complete expansion for a De Laval turbine of given power tell how you would allow for friction in the nozzle. State what modifications would be required for the throat and outlet diameters.

250. Calculate the throat and outlet diameters for a turbine nozzle which receives steam at 102 lbs. absolute superheated 80° and delivers .2 lb. per second at 1.5 lbs. absolute. Assume no friction loss up to the throat and 15 per cent at outlet.

251. Show that the circumferential velocity c may be considerably reduced, without loss of efficiency, by the use of two turbine wheels on the same shaft, the steam discharged from the first wheel being properly guided to the vanes of the second wheel. Draw the velocity diagram for the combination, assuming that in both wheels the vane angle is 30° both at entrance and at exit.

252. Deduce an expression for the velocity of a jet of steam, originally superheated, flowing through a nozzle. Define all the literal quantities in the resulting equation. Give all the formulæ which would be necessary to obtain a numerical evaluation of this expression.

253. A throttle valve reduces dry steam of 120 lbs. gage to 100 lbs. gage. Find the increase in entropy per pound. If the lowest available pressure is 2 lbs. absolute, how many B.t.u. per pound have been wasted by throttling?

254. The total friction loss in a steam nozzle is 15 per cent while the loss at the throat is but 2 per cent. The transmission efficiency between jet and blades is 80 per cent, and the mechanical friction losses of the turbine equal 20 per cent. The turbine develops 8.5 B.H.P. Find the minimum diameter of the nozzle when the boiler pressure is 138 lbs. absolute, the superheat 19° F., and the wheel-case pressure 14.7 lbs. absolute.

255. Air at 70° F. is stored in a reservoir of 50 cu. ft. capacity under a pressure of 350 lbs. absolute per sq. in. The air is permitted to escape to the atmosphere through a circular orifice of .50 in. diameter until the pressure drops to 100 lbs. absolute per sq. in. The orifice has a well-rounded inlet. How long did this take? Assume the heat interchange through the reservoir walls to be negligible.

256. Air escapes from a reservoir of 200 cu. ft. capacity through a small orifice of 0.05 in. diameter until the pressure drops from 30 to 5 lbs. gage. How much time is required for this operation, assuming the drop in temperature to be negligible? The temperature of the air is 70° F.

257. While air flows from a storage tank of 150 cu. ft. capacity into the atmosphere the pressure drops from 100 to 30 lbs. absolute. The initial temperature was 70° F., the final temperature −20° F. The orifice was $\frac{1}{4}$ inch in diameter with rounded approach. Find the approximate time of discharge.

AIR AND INTERNAL COMBUSTION ENGINES.

290. Describe some form of hot-air engine which works in combination with a regenerator.

291. The clearance space of a 6½-inch × 11-inch Otto gas engine was found to hold 5 lbs. of water at 70° F. Find the ideal efficiency of the engine.

292. The clearance of a four-cycle gas engine is 39 per cent of the piston displacement. During a 45-minute test 224 cu. ft. of gas were used in developing 12.2 I.H.P. The heat of combustion of the gas was 770 B.t.u. per cu. ft. Find the heat consumption per H.P. per hour. What part of the ideal efficiency was realized?

293. A formula often used for predicting the approximate B.H.P. of four-cycle, automobile engines running at 1000 ft. piston speed is H.P. $= .4\,d^2n$, where d is the cylinder diameter in inches and n the number of cylinders. If the friction losses are 15 per cent of the I.H.P., what mean effective pressure does the formula imply?

294. In a Diesel engine the compression ratio is $\frac{1}{12}$. If compression begins with the cylinder full of air at 180° F. and 14.2 lbs. absolute per sq. in., and no air is lost by leakage, what are the temperature and the pressure when the piston reaches its top center? Assume that during compression $Pv^{1.37}$ is constant.

295. Prove that the efficiency of the Carnot cycle is $1-\left(\frac{1}{r}\right)^{.405}$, where $\frac{1}{r}$ is the adiabatic "compression ratio," i.e., the ratio of the minimum volume to the volume before adiabatic compression.

296. Plot to scale the changes in pressure and volume of a pound of air working on the Carnot cycle between temperature limits of 0° and 1000° F. Make the maximum volume 12 cu. ft. and the minimum volume .5 cu. ft. Make the scale of volumes 2 cu. ft. per in. and the scale of pressures 100 lbs. per sq. in. per in.

297. In a calorific test of gas 2.25 kg. of water passed through the calorimeter while 0.2 cu. ft. of gas was consumed. The mean temperatures of the water are at inlet 10.36° C., at outlet 24.22° C. 26 grams of condensed vapor were collected for each cubic foot of gas consumed. The temperature of the gas was 18° C. The barometer stood at 29.31 ins., and the water gage on the meter showed a gas pressure of 1.5 ins. of water above atmosphere. Find the higher and lower calorific values of the gas per cu. ft. as supplied, and deduce the corresponding values per cu. ft. at standard pressure and temperature. Assume that a gram of water in condensing and cooling gives up 0.6 major calorie.

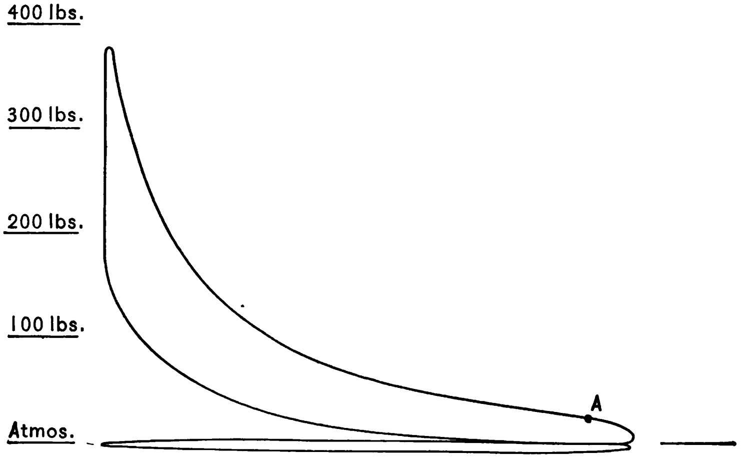
298. Explain three methods of introducing and igniting the fuel charge in oil engines. Discuss each method in connection with variations in power and speed and also with reference to possible variation in the quality of oil.

299. The compression space of a 4-in. × 4-in., four-stroke cycle, gasoline engine is one-third of the piston displacement. The engine developed 20 per cent efficiency. State the principal reasons why the actual efficiency differs so much from that of the air standard cycle.

300. The performance of an internal combustion engine is usually referred to the case of an engine following the same cycle and using a perfect gas as the working fluid. Describe the results of recent investigations upon the properties of the explosive mixture used in an internal combustion engine, and the way in which these properties differ from those of an ideal gas.

301. What is the ideal cycle for constant length stroke internal combustion engines? What effect does the size of the clearance space have upon its efficiency? Demonstrate graphically. In what ways does the character of the fuel impose limitations upon the attainment of high efficiencies?

302. In a gas engine giving the annexed diagram the mean temperature of the charge at the end of the suction stroke is 250° F. and its pressure is 14.7 lbs. per sq. in. The compression space is .185 of the stroke volume. Neglecting the contraction occurring in combustion, find the temperature at the point *A*, when the exhaust valve opens. Also find the temperature of the gas left in the cylinder when the pressure has fallen to atmospheric, after the opening of the exhaust valve. It may be assumed that no heat is lost or gained during the fall of pressure and that the mean ratio of the specific heats is 1.25.



303. A 4-cycle Diesel engine with 6 single-acting cylinders of 15¾-in. bore and 23¼-in. stroke develops 500 B.H.P. at 180 revolutions per minute. What is the mean effective pressure based on the brake output?

304. The engine in problem 303 uses .50 lb. of fuel oil per B.H.P. hour. The oil is composed as follows: Carbon 83.3 per cent, hydrogen 12.4 per cent, oxygen 3.8 per cent. Find the ratio between the volume of air at 32° F. required for chemical combustion of a lb. of oil, and the piston displacement during suction strokes, per lb. of oil. Explain the difference in these volumes.

305. On the assumption that the specific heats of a gas-engine mixture vary linearly and are expressed by the equations $c_p = a + nT$, $c_v = b + nT$, where T is the absolute temperature and a, b, and n are constants, show that the law of adiabatic expansion is given by

$$pv^{\frac{a}{b}} \epsilon^{n\frac{T}{b}} = \text{constant},$$

and determine an approximate expression for the efficiency of an engine using this mixture in terms of the extreme temperatures if the heat is taken in and rejected at constant volume.

306. Sketch and describe some form of optical indicator suitable for indicating high-speed, internal-combustion engines.

307. In a 2-cycle engine where the charge is drawn through the carburetor into the crank case, the pressure in the cylinder at termination of compression is 55 lbs. above atmosphere. The engine uses 1.6 lbs. of gasoline per B.H.P. hour. The "higher heat of combustion" of the fuel is 21,100 B.t.u. per lb. Calculate the thermal efficiency from the fuel to the shaft, and mention the possible causes which make this efficiency so low in comparison with other internal-combustion engines.

Suppose the volume of the clearance space in terms of piston displacement is not given. Assuming a probable rate of increase in pressure during compression, calculate the "compression ratio" and then the efficiency for the "air standard cycle." Compare this with the actual efficiency as determined by the test.

308. In forming the heat balance of a gas-engine test, the heating value of the gas used is put on one side and the three items,

(1) Work done,
(2) Heat carried away by jacket water,
(3) Heat carried away in exhaust gases,

on the other. Item (3) is measured by an exhaust-gas calorimeter, in which the gases are cooled to about 50° F. Should the "higher" or the "lower" calorific value of the gas be taken in calculating the heating value, and should brake work or indicated work be taken for item (1)? Give full reasons for your answers.

THE STEAM ENGINE AND THE RANKINE CYCLE

340. Find the steam consumption in lbs. per H.P. per hour of an engine working upon the Rankine cycle between a boiler pressure of 200 lbs. absolute and a condenser pressure of 1 lb. absolute. The boiler steam contains 2 per cent moisture. What is the thermal efficiency?

341. A steam engine uses 20 lbs. of steam per H.P. per hour. The boiler pressure is 100 lbs. gage; the initial priming 1 per cent, and the temperature of the feed water 180° F. Find the B.t.u. required per H.P. per minute and the cylinder efficiency.

342. The following data are from the results of an engine test:

Output	172 I.H.P.
Steam pressure	140 lbs. sq. in. gage.
Vacuum	27.5 ins.
Steam used	2540 lbs. per hour.
Quality	dry.

Calculate the heat supply per I.H.P. per minute for this engine and for a Rankine engine between the same limits, and deduce the relative efficiency.

Calculate also the steam used per I.H.P. per hour in the actual engine and in the Rankine engine.

343. Calculate the thermal efficiency of a nonconducting steam engine supplied with dry steam at 135 lbs. absolute pressure and exhausting at 8 lbs. absolute pressure. Find the B.t.u. consumption per H.P. per minute.

344. A steam engine uses 20 lbs. of steam per I.H.P. per hour at 120 lbs. pressure absolute with 2 per cent priming. The temperature of the feed water is 170° F. Find the B.t.u. per H.P. per minute and the cylinder efficiency.

345. The steam consumption of an engine is 15.5 lbs. per I.H.P. hour. The steam supplied at the throttle is dry, at 135 lbs. absolute pressure. The temperature in the exhaust pipe is 102° F. Determine the B.t.u. consumption per I.H.P. per minute and the thermal efficiency.

346. A test on a compound steam engine was run under the following conditions: Boiler pressure 102.1 lbs. gage, priming 1.0 per cent, vacuum 24.4 ins., barometer 29.2 ins., total I.H.P. 104.6, B.t.u. per H.P. per minute 386.

Find the steam consumption in lbs. per H.P. per hour and the thermal efficiency. What would be the efficiency if the engine worked upon the Rankine cycle?

347. A test on a triple-expansion, pumping engine gave these data:

Boiler pressure 175.7 lbs. gage, quality of steam 0.988, vacuum 27.25 ins., barometer 14.85 lbs., total I.H.P. 576, B.t.u. per H.P. per minute 294. What were the ideal and actual efficiencies, the cylinder efficiency, and the ideal and actual steam consumption?

348. The following figures are taken from a combined boiler and engine test.

Boiler pressure	150 lbs. per sq. in. absolute.
Dry steam in the boiler and at the throttle.	
Temperature of feed water	70° F.
Water evaporated per lb. of coal	8.82 lbs.
" " " I.H.P. per hour	21.6 lbs.
Calorific value of coal	14,250 B.t.u. per lb.

Find the efficiency of the boiler alone and the efficiency of the plant as a whole.

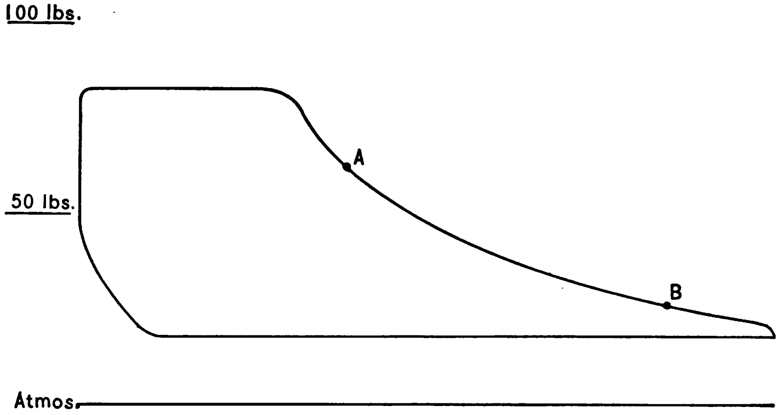
The pressure in the exhaust pipe is that of 4 ins. of mercury. What is the efficiency of the engine, if its heat supply be reckoned from water at the temperature of the exhaust?

349. An engine is required to work at the rate of 500 I.H.P. with a piston speed of 500 ft. per minute. Assuming that cut-off is to take place at ¼ stroke, that the expansion curve is a rectangular hyperbola, that the initial pressure is 140 lbs. per sq. in. absolute, and that the back pressure is 5 lbs. per sq. in. absolute, calculate the size of the cylinder and the number of revolutions per minute, the stroke being taken equal to twice the diameter. Assume that there is no compression and neglect the effect of clearance. Assume also sharp corners on the indicator diagram at cut-off and at release.

350. In what ways does a condenser affect the economy of an engine? Describe the different methods of *producing* and *maintaining* a vacuum.

351. What is the function of a cooling tower?

352. The following diagram is from the head end of a Corliss steam engine, 18 by 36 ins., running at 85 R.P.M. The head-end clearance is .47 cu. ft. The barometer read 29.7 ins. The weight of substance exhausted from the head end per revolution was .635 lb. Find the net quantity of heat transferred from the metal to the steam during that part of the expansion between *A* and *B*. Preface your calculation by an explanation of the principles involved and a statement of whatever assumptions you make that are open to question. Consider in particular the effect of possible leakage of steam past either the admission or the exhaust valve, or past the piston.



353. (*a*) Sketch and describe the indicator cards obtained from a nonreceiver, compound steam engine.

(*b*) What is the effect, upon the total H.P. of a compound engine and upon the distribution of the work between the cylinders, of varying the cut-off in either the high- or the low-pressure cylinder?

354. Calculate the probable H.P. of a Corliss engine, condensing, with cylinder 20 ins. in diameter, 36-in. stroke, cut-off at $\frac{3}{10}$ stroke, clearance 10 per cent, compression 15 per cent, boiler pressure 100 lbs. absolute, back pressure 3 lbs. absolute, piston speed 600 ft. per minute.

355. A Corliss engine, 20 ins. by 30 ins., running at 110 R.P.M., receives steam at 95.3 lbs. gage and exhausts at 0.3 lb. gage. The clearance is 10 per cent. Compression is at 15 per cent of the stroke. With cut-off at .3 of the stroke, what is the I.H.P.? Assume a diagram factor of .9 in calculating the probable M.E.P.

356. An engine used 13 lbs. of steam per H.P. hour. The boiler pressure and temperature were 140 lbs. gage and 460° F., respectively; the vacuum was 28 ins. and the barometer 30 ins. What part of the Rankine efficiency was attained? How many B.t.u. were lost per H.P. per minute due to heating the cylinder, radiation, etc.?

357. Write equations for the interchange of heat between the steam and the walls of a cylinder during expansion; during exhaust.

358. Make use of the $T\phi$ diagram in discussing the nature and the relative magnitudes of the heat losses in the cylinders of a simple engine and of a compound engine of the same power, working between the same boiler pressure and back pressure, and running at the same speed.

359. Give different methods of improving the economy of steam engines. Explain fully the way each method acts in order to effect this economy. State conditions of maximum and minimum saving for each case.

360. Explain why there is a practical limit to the extent to which expansion can be carried with advantage in a steam engine, though in theory the steam consumption per I.H.P. hour diminishes indefinitely as expansion is increased. Why is the limit higher in a compound than in a simple engine?

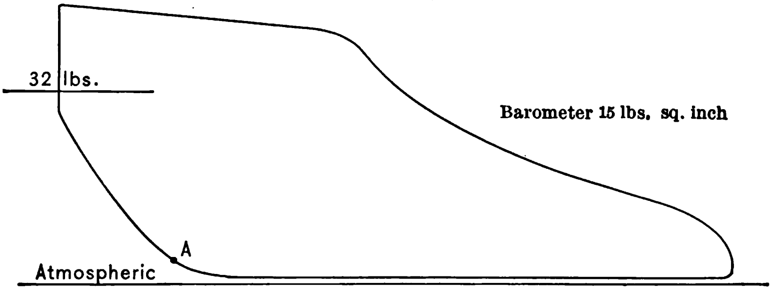
361. Why is the maintenance of a good vacuum of much greater relative importance in the working of a steam turbine than in a reciprocating engine?

362. Why is a compound engine required in order to take advantage of high-pressure steam? Discuss fully the different factors bearing upon this.

363. Discuss the action of a steam jacket as applied to a simple Corliss engine with cut-off at ¼ stroke, describing its effect on economy, initial condensation, and rate of decrease in pressure during expansion.

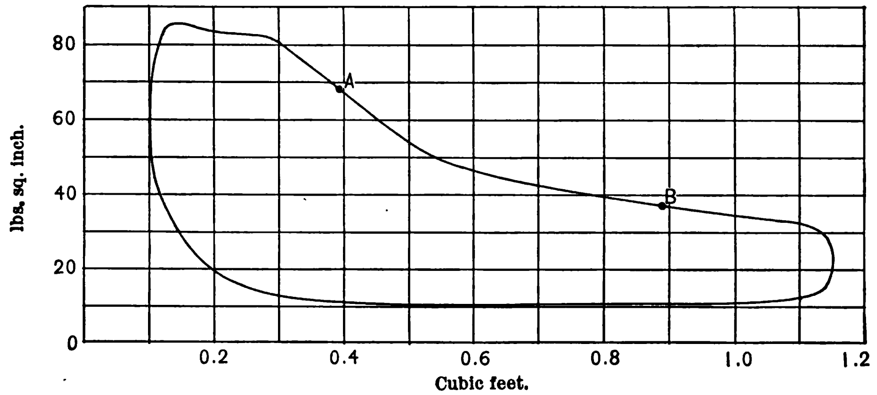
364. A tandem compound steam engine requires 17.5 lbs. steam per I.H.P. hour, the pressure being 138 lbs. absolute, with 48° of superheat, and the exhaust pressure 2.6 lbs. absolute. Compare the efficiency of this engine with that of the Rankine cycle between the same limits.

365. The accompanying diagram was taken from an engine in which the cylinder is 8½ ins. diameter and 1.2 ft. stroke, and the clearance space is ten per cent of the piston displacement. To these data and the particulars on the diagram add the axes of pressure and volume, and find the weight of steam present at the point marked A, assuming it to be dry and saturated.



366. There was present during expansion in the cylinder from which the annexed diagram was taken, a weight of 0.11 lb. of steam. Find its dryness fraction at the points *A* and *B*, and calculate the change in the internal energy of the steam between the points *A* and *B*.

Also find the external work done by the steam between these points and deduce the net amount of the heat exchange between the steam and the walls during this part of the stroke.



367. Calculate the probable indicated horse power of a double-acting triple-expansion steam engine having four cylinders 20–40–(2) 50 by 60 ins., running at 80 revolutions, supplied with steam at 165.3 lbs. gage; with 2 lbs. absolute pressure in the condenser; cut-off in high-pressure cylinder at ½ stroke. Use a multiplier for M.E.P. of 0.7. Find the points of cut-off in the intermediate and low pressure cylinders.

368. The steam consumption of a certain locomotive is 35 lbs. per I.H.P. hour; that of a modern triple-expansion pumping engine, 11.2 lbs. per I.H.P. hour. Discuss all the differences in mechanical construction and in the conditions of operating that lead to such a difference in economy.

STEAM BOILERS AND AUXILIARIES

390. What is meant by a boiler H.P.? How does it differ from an engine H.P.?

391. What are the requirements of a good boiler? Explain fully the function of each part. Using standard types of boilers as illustrations, show how certain of these requirements are but imperfectly realized.

392. Sketch and describe a horizontal, return-tube boiler and some form of large-tube, water-tube boiler, showing position of grates, circulation of gases and water, and location of steam, feed, and blow-off pipes. Give two advantages of the use of water-tube boilers, and state under what conditions their use is imperative.

393. A boiler H.P. is equivalent to 30 lbs. of water fed at 100° F. and evaporated under 70 lbs. gage pressure. How many thermal units does this represent per hour?

394. A test of an engine and boiler shows 1.05 lbs. coal consumed per B.H.P. hour. The heat of combustion of the coal is 14,000 B.t.u. per lb. What is the thermal efficiency of the plant?

395. What is the probable error due to the coal, in a boiler test lasting 10 hours, with running start and finish? The grate area was 60 sq. ft. and 600 lbs. of coal were burned per hour.

396. A test on a boiler plant gave the following data:

Duration of test	100 hours.
Total dry coal	900,000 lbs.
Total water fed	8,100,000 lbs.
Temperature of feed	222° F.
Quality of steam	0.97.
Boiler pressure (gage)	150.3 lbs.
Heating value of coal per lb.	14,520 B.t.u.
Total grate area	450 sq. ft.

Find equivalent evaporation per lb. of coal from and at 212°. If the test were made with "running start" and a "running finish," and a total error of 1½ ins. were made in estimating the thickness of the fires, what was the accuracy of the test?

397. Calculate the size of the steam pipe for a 2000-H.P. boiler delivering steam at a maximum pressure of 150 lbs. and a minimum pressure of 115 lbs. absolute.

398. Describe a "primary" heater, a "secondary" heater, an economizer, and a superheater. How does each affect the economy of the plant?

399. 20,000 lbs. of steam per hour, at 150.3 lbs. gage, and containing 2 per cent of moisture, are superheated 250° in a separately-fired superheater. The thermal efficiency of the superheater is 65 per cent and the coal has a heating value of 14,400 B.t.u. per lb. How many lbs. of coal are needed per hour?

400. What is boiler scale? Describe the experiments you would make in order to determine whether a water would or would not give a scale. Discuss the methods of preventing or minimizing such a deposit, either by treatment within the boiler or by previous treatment of the water.

401. Assume that the velocity of steam in the pipes entering and leaving the superheater in problem 399 is to be 5000 ft. per minute; what should be the cross-sectional area at entrance and at exit?

402. Exhaust steam (containing 10 per cent water) at 2 lbs. absolute pressure is condensed in a surface condenser and discharged by the wet pump at 96° F. The circulating water enters at 70° and leaves at 95°. How many lbs. of cooling water are needed per lb. of steam? If there were no air in the condenser, what would be the lowest pressure possible in condenser?

403. A boiler contains 30 lbs. of steam and 11,970 lbs. of water. The fires are banked and feed and steam valves shut. At the time of banking the pressure was 150 lbs. absolute. Twelve hours later the pressure was 70 lbs. absolute. The banked fire had by its slow burning given 770,000 heat units to the boiler during the 12 hours. How much heat was lost from the boiler by radiation and conduction during the 12 hours?

404. Calculate (1) equivalent evaporation from and at 212° F.; (2) boiler H.P.; (3) efficiency of boiler plant, from the following data: coal per hour 5000 lbs., water per hour 40,000 lbs., boiler pressure 140 lbs. absolute, temperature of steam 453.09° F., temperature of feed water 250.0° F., heat of combustion of coal 14,300 B.t.u.

If the boilers are operated with natural draft, what should be the grate surface; heating surface; flue area?

405. A battery of 4 horizontal multitubular boilers receives feed water at 102° F. and produces dry steam at 120.3 lbs. gage. The heating surface of each boiler is 1900 sq. ft. and the grate measures 6 ft. by 8 ft. With natural draft, about how many lbs. of water per hour would be evaporated by the whole battery? What would be the combined boiler H.P. and what the coal consumption per day of 24 hours?

406. A horizontal multitubular boiler of 100 H.P. (A.S.M.E. rating) uses coal of a heating value of 14,000 B.t.u. The boiler efficiency is 70 per cent. How much coal is burned per hour? Determine the grate area, heating surface, and flue area for natural draft. How much air is required per hour?

407. Two boilers supply steam to the same main, one generating 7500 lbs. of steam per hour, containing 3 per cent priming, the other 4000 lbs. per hour, superheated 150°. The pressure in the main is 120 lbs. gage. What is the quality of steam in the main?

408. Sketch a method of staying the heads of a horizontal multitubular boiler.

409. Explain how the diameter of a safety valve for a boiler should be calculated.

410. A boiler consumes 500 lbs. of anthracite coal per hour. The chimney gases yield on analysis

CO_2 = 12 per cent, by volume
O = 9 per cent, " "

Assuming that the coal is pure carbon, find the weight of air used per hour. Also find the velocity of the gases at the base of the chimney if their temperature is 500° F., the area of the chimney being 10 sq. ft. and the barometer normal.

(Air weighs .08 lb. per cu. ft. at a temperature of 32° F. and under normal atmospheric pressure. It contains 23 per cent by weight of oxygen. The atomic weight of carbon may be taken as 12 and that of oxygen as 16.)

411. A cylindrical boiler of 260 cu. ft. capacity shut off from the main contains 9600 lbs. of mixture at 150 lbs. absolute pressure. How much heat must be lost by radiation in order for the pressure to drop to 20 lbs. absolute?

412. A certain boiler apparently evaporates 9 lbs. of water per lb. of coal burned. The feed temperature is 100° F. The boiler makes steam at 185.3 lbs. gage, superheated 50°. The coal used has a heating value of 14,600 B.t.u. per lb. What is the thermal efficiency of the boiler?

413. Make a sketch of a cooling tower. On what principle does it operate? When and for what purpose is a cooling tower used and what gain is made by using it?

414. Describe two types of condensers.
In what ways may the use of a condenser improve the economy of an engine?

415. An analysis of coal gives carbon 78 per cent, hydrogen 3.5 per cent, oxygen 6 per cent. Find the oxygen required for the complete combustion of 1 lb. of the coal and the necessary air supply to the furnace per lb. of coal. Find also the gross calorific value of the coal and the net value when allowance is made for the loss due to the evaporation of the water in the furnace gases. Take the calorific value of carbon as 14,500 B.t.u. and that of hydrogen as 62,160 B.t.u. per lb.

416. A boiler has 20 sq. ft. of grate area and burns 25 lbs. of coal per sq. ft. per hour. The pressure carried is 140 lbs. absolute. Find the size of safety valve needed, assuming a lift of .1 in.

417. A boiler having a grate 5 ft. by 6 ft. works with forced draft, and 30 lbs. of coal are burned per sq. ft. of grate per hour. The pressure carried is 140 lbs. absolute. Find diameter of safety valve needed.

418. A superheater, separately fired, superheats 100,000 lbs. of steam per hour at 150 lbs. absolute pressure on sq. in. The steam enters the superheater with 3 per cent moisture; it leaves, superheated 150°. 1,250 lbs. of coal are burned per hour to do this. The heat of combustion of the coal is 14,500 B.t.u. per lb. What is the thermal efficiency of the superheater?

419. A battery of boilers fired with California crude oil having a calorific value of 18,500 B.t.u. per lb. (higher heating value) evaporated 12.26 lbs. of water per lb. of oil. The feed temperature was 132° F. The steam pressure by gage was 145 lbs. The steam was superheated 85°. The fuel was fed and atomized by steam jets supplied from the same boilers, and it was found that 1.8 per cent of the total steam produced was required for this purpose. What was the net efficiency of boilers and burners combined?

COMPRESSED AIR

450. What is the minimum amount of work theoretically required per lb. of dry air to draw it from the atmosphere at 14 lbs. absolute and 70° F., and deliver it to a receiver at 98 lbs. absolute, cooling water being available at 70° F.?

451. One thousand cu. ft. of free air per minute are compressed from 14.7 to 147 lbs. absolute, in a two-stage compressor. Each cylinder compresses along a line having the equation $pv^{1.3}$ = a constant. The intercooler between the two cylinders reduces the temperature to that of the intake air. Find the minimum indicated horse power required at the compressor cylinder.

452. An air compressor takes in 100 cu. ft. of free air per minute at 14 lbs. absolute pressure per sq. in. and compresses it to 280 lbs. absolute on the sq. in. The compression curve has the equation $pv^{1.3}$ = a constant. How much power will indicator cards taken from the compression cylinder show? If the mechanical efficiency of the compressor and the steam engine driving it is 85 per cent, how many H.P. should the steam cylinders indicate?

453. A thousand cu. ft. of free air per minute are compressed to 279.3 lbs. gage by a two-stage compressor driven by a steam engine. In each cylinder the rise in pressure is shown by $pv^{1.3}$ = a constant. The atmospheric temperature and that of air leaving the intercooler is 70° F. Assuming a displacement efficiency of 95 per cent and a combined mechanical efficiency of 90 per cent, determine the proper pressure for the air in the intercooler and the I.H.P. of air and steam cylinders. Compare the I.H.P. of the air cylinders with that for isothermal compression.

454. Calculate the H.P. required to drive an air compressor supplying 100 cu. ft. of free air per minute at 90 lbs. absolute. The compression follows the law $pv^{1.3} = c$, the mechanical efficiency = 90 per cent, and atmospheric pressure = 15 lbs. What is the "air efficiency" of the compressor?

455. An air compressor delivers 55 cu. ft. of free air per minute into some storage tubes of 50 cu. ft. capacity. The tubes originally contained air at atmospheric conditions, barometer 30 ins., temperature 70° F. How long will it take the compressor to increase the pressure in the tubes to 2500 lbs. per sq. in., provided the mean temperature of the air in the tubes is then 50° F. above that of the atmosphere?

456. In the Taylor hydraulic air compressor, air is drawn vertically downward, in small bubbles, in a current of water (see Illustrations of Engines, Plate XL). The temperature of the water is 40° F. The weight per cu. ft. is 62.4. How much work is done per lb. of air in compressing it to 50 lbs. gage? What is the depth of submergence required? Discuss the varying buoyancy of the air and the work done in overcoming it.

457. In a single-cylinder air compressor, air is compressed adiabatically from pressure p_1 to pressure p_2, the temperature rising from T_1 to T_2. Sketch the p–v and the T–ϕ diagrams. If now the compression be carried out in two adiabatic stages, the air, while passing from one cylinder to the other being cooled, at constant pressure, to the temperature T_1, sketch again the p–v and the T–ϕ diagrams and show that the product of the final temperatures of the two compressions is constant and that the expenditure of work in compression is least when these temperatures are equal.

Similarly if the compression be carried out in three adiabatic stages, with cooling at constant pressure to temperature T_1, between cylinders 1 and 2, and again between cylinders 2 and 3, sketch the diagrams and show that the product of the final temperatures of the three compressions is constant and that the expenditure of work is least when these three temperatures are equal.

458. The capacity of a certain line of pipe containing dry air at the temperature and pressure of the surrounding atmosphere is 100 cu. ft. The pipe is to be pumped out to a vacuum of 27 ins., by a 6-in. by 12-in. single-acting air pump, with 1 per cent clearance, running at 120 R.P.M. The thermometer reads 60° F. and the barometer 30.0 ins. Water for cooling is available at 60° F. For comparison with the work actually required to do the pumping, as found by a test of the apparatus used, and in order to express the relative efficiency of the pump, what should be regarded as the ideal or minimum amount of work theoretically required?

REFRIGERATION AND HEATING

480. Describe the ordinary cycle of the working substance in a vapor-refrigerating machine in which expansion takes place through a nozzle.

481. In a plant in which air follows a reversed Joule cycle the compressing cylinder takes in air at atmospheric pressure of 14.7 lbs. per sq. in., and delivers it at a pressure of 90 lbs. absolute per sq. in. At the beginning of compression the temperature is 30° F., and at the beginning of expansion it is 60° F. Determine the highest and lowest temperatures in the cycle and the work expended per lb. of air. Take $k = 1.4$.

482. An ammonia-refrigerating machine is working between temperatures 100° F. and −35° F., the vapor being dry at the end of adiabatic compression. Describe the cycle through which the working substance passes, and sketch the T–ϕ diagram (1) when expansion takes place adiabatically in a cylinder; (2) when expansion takes place through a nozzle. Find in each case the amount of heat absorbed by the ammonia at the low temperature and the coefficient of performance.

Take the specific heat of liquid ammonia as 1.1 and the latent heat at t° F. as $540 - 0.8\ (t - 32)$.

483. Five buildings each 300 ft. long, 60 ft. wide, and 70 ft. high are to be heated by direct steam heating. The air in the buildings is changed once an hour. The walls of the buildings are 35 per cent glass. The inside temperature is to be maintained at 70° when the outside temperature is 0°. What is the total amount of radiating surface needed and what boiler H.P. would be needed? What would be the probable coal consumption per 24-hour day, assuming the mills to be kept at 70° during a period of zero weather?

484. Find the drop in pressure in a 12-in. steam pipe (well covered) 500 ft. long, delivering 96,000 lbs. of steam per hour, the steam being at 150 lbs. absolute pressure and containing 1 per cent of moisture.

485. A line of 2-in. pipe (uncovered) 250 ft. in length leads from a boiler to a number of steam-driven drills in a quarry. The pressure carried in the boiler is 120 lbs. absolute. The temperature of the outside air is 40° F. What boiler H.P. is lost by radiation from this uncovered pipe? If this pipe had been covered with one of the standard sectional coverings, what would have been the loss in boiler H.P.?

486. Two refrigerating machines, one using sulphur dioxide and the other ammonia, work between the same limits of temperature, viz., 50° F. to −30° F. In each case the vapor is dry and saturated at the end of compression, and expansion takes place through a throttling valve. Determine in each case the refrigerating effect per lb. of substance used and the coefficient of performance.

Also show that if the machines are to have the same refrigerating effect per stroke, the volumes of their compressing cylinders must be approximately in the ratio of 11 to 4.

487. An ammonia-compression machine, steam-driven, working with the brine system, cools 1560 lbs. of brine per minute from 37° F. to 27° F. The specific heat of the brine is .75. The ammonia leaves the expansion coil at 15.04 lbs. gage and at 35° F. The pressure of the ammonia leaving the compressor is 164.94 lbs. gage. The temperature of the liquid ammonia entering the expansion coil is 90° F. The ammonia enters compressor at 41° F.

Find the power required by the compressor cylinder and, neglecting clearance, calculate the diameter of the cylinder, assuming the cylinder to be single-acting, of 30-in. stroke, and to make 65 working strokes per minute. What is the weight of the liquid ammonia circulated per minute?

Assuming 80 per cent mechanical efficiency, what is the power needed at steam cylinder? The steam cylinder is double-acting, has Corliss valves, is supplied with steam at 100.3 lbs. gage, and exhausts at 1.3 lbs. gage. The cut-off is at 40 per cent, compression 10 per cent, clearance 10 per cent. If the steam cylinder is 36-in. stroke, what should be its diameter?

488. Find the number of heat units absorbed at the low temperature per lb. of working substance, and the volume of the compressing cylinder per thousand units of heat absorbed, in the case of (1) ammonia, (2) sulphurous acid, when the limits of temperature are 50° F. and −30° F., the vapor in both cases being dry at the beginning of compression. What is the refrigerating efficiency for each substance?

ANSWERS

THE LAWS OF THERMODYNAMICS AND DEFINITIONS OF EFFICIENCY

1. 2545 B.t.u.

2. Efficiency = 13.05 per cent.

3. Efficiency = 56.9 per cent.

4. Ratio of actual to Carnot efficiency = 0.648.

5. Discussion.

6. Heat supplied at 1252° F.; heat rejected at 752° F.

7. Efficiency = 13.9 per cent.

8. Thermal efficiency of I.H.P. = 13.17 per cent; per cent of Carnot efficiency realized = 58.7; electrical H.P. = 0.696 I.H.P.

9. Reported efficiency = 56.8 per cent; Carnot efficiency = 58.3 per cent; economy improbable.

10. Change in internal energy = 37,220 foot-pounds = 47.8 B.t.u.

11. 0.00353 unit of entropy.

12. Heat supplied = 1920 B.t.u.; change in entropy = 2.0 units.

13. Efficiency = 23.0 per cent; work = 5370 foot-pounds; heat rejected = 23.1 B.t.u.; change in entropy = 0.0153 unit.

14. Area of indicator card = 2.4 B.t.u. = 1867 foot-pounds.

15. Efficiency = 29.1 per cent; heat received = 172 B.t.u.; heat rejected = 122 B.t.u.; work per cycle = 38,900 foot-pounds.

16. Increase in internal energy = 896.9 B.t.u.; increase in entropy = 1.44 units.

17. Change in entropy = 0.723 unit.

18. Change in internal energy = 576,000 B.t.u.; increase in entropy = 863.6 units.

19. Heat lost = 2705 B.t.u.; decrease in entropy = 4.69 units.

20. Increase in entropy = 0.1990 unit, assuming the specific heat of water equals unity.

21. Initial efficiency = 82.0 per cent; final efficiency = 35.3 per cent; discussion.

22. 166° F.

THERMODYNAMICS OF GASES

40. 547 lbs. of air.

41. 0.99 lb. of oxygen.

42. 195.8 ins. of mercury.

43. 29.1 lbs. per tank; volume before compression 370.5 cu. ft.

44. Difference in weight = 24.0 lbs.; volume of each = 287 cu. ft.

45. Volume of hydrogen tank = 116.2 cu. ft.; oxygen tank = 58.4 cu. ft.

46. 97.7 per cent of air removed.

47. 34.1 lbs.

48. Pull on rope = 830 lbs.; barometer = 25.6 ins.

49. Barometer = 24 ins.; difference in pressure = 0 lbs.; pull on rope = 20 lbs.

50. Entropy less by 203 units; internal energy greater by 2,500,000 foot-pounds.

51. Increase in internal energy = 5050 foot-pounds; increase in entropy = 0.0091 unit.

52. 755.5° F.; increase in internal energy = 95,200 foot-pounds.

53. Work = 57,300 foot-pounds; heat added = 255 B.t.u.; increase in entropy = 0.3639 unit.

54. Initial temperature = 485° F.; final temperature = 1025° F.; increase in internal energy = 142,100 foot-pounds; increase in entropy = 0.1523 unit.

55. Heat added = 16,320 B.t.u.; final temperature = 1218° F.

56. Increase in entropy = 0.423 unit.

57. Work done = 142,300 foot-pounds; change in internal energy = 0; heat added = 183 B.t.u.

58. Heat added = 573.3 B.t.u.; change in entropy = 1.024 units.

59. Work done = 4,140,000 foot-pounds; heat added = 5320 B.t.u.

60. Work done = 3,610,000 foot-pounds; final temperature = −36.5° F.

61. Work done = 4,810,000 foot-pounds; heat removed = 6180 B.t.u.

62. Heat received = 1,482 B.t.u.; work done = −26,000 foot-pounds.

63. Initial temperature = 80° F.; final temperature = 620° F.; change in internal energy = 1,420,000 foot-pounds; increase in entropy = 3.29 units; heat added = 2568 B.t.u.

64. Work done = 85,400 foot-pounds.

65. Proof.

$$\textbf{66.}\ \text{Heat added along}\begin{cases} ab = +193.0 \text{ B.t.u.} \\ bc = -\ \ 91.5 \quad '' \\ cd = +\ \ 51.3 \quad '' \\ de = -193.0 \quad '' \\ ea = +\ \ 91.5 \quad '' \end{cases}$$

$$\text{Total heat added} \quad = +\ 51.3 \quad ''$$

Total work done per cycle = 39,900 foot-pounds.

67. Heat added = 70 B.t.u.; external work done = 54,400 foot-pounds; increase in entropy 0.0998 units.

68. External work done = 17,400 foot-pounds.

69. Change in entropy = 0.355 units; change in internal energy = 426,400 foot-pounds.

70. Work required = 5420 foot-pounds.

71. External work done = 158,000 foot-pounds.

72. $PV^{1.16} = 28,800$.

73. Work done = 191,500,000 foot-pounds; heat added = 246,400 B.t.u.; increase in entropy = 280 units.

74. Work done = 93,800,000 foot-pounds = change in internal energy; final temperature = −65° F.

75. Work done = 97,300 foot-pounds; heat added = 434 B.t.u.; increase in entropy = 0.67 unit.

76. Plot.

77. Plot.

78. Heat removed = 1711 B.t.u.; decrease in entropy = 2.96 units.

79. Heat absorbed = 591 B.t.u.; change in entropy = 1.15 units.

80. Proof.

81. Loss of intrinsic energy per pound of air = 10,500 foot-pounds; final velocity = 2.1 per cent less than initial.

82. Heat added per pound = 5.92 B.t.u.

83. Heat lost per pound = 5.32 B.t.u.

84. Change in volume = 8.69 cu. ft.; change in internal energy = 13,280 foot-pounds; change in entropy = 0.0615 unit.

85. Work required = 4570 foot-pounds.

86. Exponent = 1.028. Work done = 12,300 foot-pounds; heat abstracted = 14.71 B.t.u.; gain in intrinsic energy = 854 foot-pounds.

87. Work done = 1340 foot-pounds; maximum pull on piston rod = 1584 lbs.

88. Work done = 1980 foot-pounds; maximum pull on piston rod = 365 lbs.

89. Final pressure = 833 lbs. per sq. in. absolute; temperatures are −122° F. and +206° F.

90. 358.1° F.; 2.280 B.t.u.

91. Initial temperature = −91.4° F.; final temperature = 424° F.; change in internal energy = 373,000 foot-pounds; increase in entropy = 1.143 units; heat added = 673 B.t.u.

92. Heat added = 60.7 B.t.u.; external work done = 47,200 foot-pounds; increase in entropy = 0.092 unit.

93. External work done per cycle = 11,800 foot-pounds; I.H.P. = 28.6.

SATURATED AND SUPERHEATED VAPORS—USE OF STEAM AND ENTROPY TABLES AND PLOTS

130. Heat supplied per pound = 1128.1 B.t.u.
131. Heat required = 22,040 B.t.u.
132. Volume = 53.36 cu. ft.
133. Increase in intrinsic energy = 20,380 B.t.u.
134. Final temperature = 73.3° F.
135. Heat required = 1729 B.t.u.
136. Pressure = 98.8 lbs. per sq. in. absolute; volume of boiler = 22.73 cu. ft.
137. Heat supplied per pound = 1043 B.t.u.; work developed per pound = 64,800 foot-pounds; change in entropy = 1.3147 units.
138. Per cent moisture present = 11.8; quality = 0.882.
139. Increase in volume = 6.5 cu. ft.; increase in intrinsic energy = 633,000 foot-pounds; increase in entropy = 1.177 units.
140. Entropy = 0.79 unit.
141. Increase in entropy = 3.060 units.
142. Intrinsic energy = 3,700,000 foot-pounds; total heat = 5092 B.t.u.; entropy = 6.807 units; volume = 12.9 cu. ft.
143. Heat added = 3491 B.t.u.; change in volume = 9.612 cu. ft.; change in internal energy = 2,520,000 foot-pounds; change in entropy = 4.5576 units.
144. Intrinsic energy = 1,504,000 foot-pounds; entropy = 2.785 units.
145. Final temperature = 73.8° F.
146. Steam required per minute = 15.08 lbs.
147. Steam required per minute = 11.43 lbs.
148. Final temperature = 96.5° F.; second solution, 95.4° F.
149. Final temperature = 62.7° F.
150. Heat lost = 545 B.t.u.
151. Pressure = 0.3627 lb. per sq. in. absolute; quality = 0.0027.
152. Heat removed = 9070 B.t.u.; final temperature = 172.5° F.; final pressure = 6.34 lbs. per sq. in.
153. Weight of steam = 0.4 lb.
154. Steam required per minute = 99.2 lbs.
155. Heat supplied per hour = 247,000 B.t.u.
156. Temperature on entering condenser = 82.4° F.
157. Initial volume = 6.88 cu. ft.; final volume = 35.78 cu. ft.; work done = 191,000 foot-pounds.
158. Final volume = 1.25 cu. ft.; change in internal energy = 3430 foot-pounds.
159. Energy liberated by steam = 19,900,000 foot-pounds; energy liberated by water = 1,072,000,000 foot-pounds.
160. Heat required = 6134 B.t.u.
161. Discussion.
162. Work done = 3,471,000 foot-pounds; final volume = 286 cu. ft.
163. Demonstration.
164. Demonstration.
165. Discussion.
166. Temperature of mixture = 82.7° F.
167. Steam condensed = 15.98 lbs.
168. Work = 247,500 foot-pounds.
169. Volume = 15.78 cu. ft.
170. Quality = 69° F. superheat; intrinsic energy = 1,765,000 foot-pounds.
171. Quality = 36.2° F. superheat.
172. Quality (final) = 220.3° F. superheat; external work done = 129,900 foot-pounds; heat added = 314.8 B.t.u.; change in entropy = 0.3544 unit.
173. Heat added = 604.5 B.t.u.; work done = 43,200 foot-pounds.
174. Dryness = 0.8940; decrease in internal energy = 74.7 B.t.u.; external work = 58,100 foot-pounds; external work for exponential equation = 58,830 foot-pounds.
175. Heat added = 551,500 B.t.u.; volume = 2125 cu. ft; increase in intrinsic energy = 513,000 B.t.u.
176. Pounds of steam needed = 1513 lbs.

177. Heat given up = 8400 B.t.u.
178. Water heated = 7.5 lbs.
179. Heat added = 803.2 B.t.u.
180. Initial volume = 7.5 cu. ft.; final volume = 48.23 cu. ft.; change in internal energy = 212,000 foot-pounds.
181. Heat added = 482 B.t.u.; change in entropy = 0.520 unit.
182. Work done = 536,400 foot-pounds; increase in entropy = 0.872 unit; increase in volume = 51.44 cu. ft.
183. Increase in volume = 0.222 cu. ft.; increase in internal energy = 24,700 foot-pounds; heat added per pound = 38.5 B.t.u.
184. Heat given up per pound = 1065.5 B.t.u.
185. Heat added = 119,300 B.t.u.; final pressure = 216.7 lbs. per sq. in. absolute; quality = 0.00625; increase in entropy = 171.3 units.
186. Work obtainable = 41,480 foot-pounds; dryness fraction = 0.8880; pressure = 32.13 lbs. absolute per sq. in.

THE FLOW OF FLUIDS

220. Discussion.
221. Discussion.
222. Steam escaping = 960 lbs. per hour.
223. Area at section when p = 40 lbs. = 0.683 sq. in.; approximate area at throat by Rankine's equation = 0.583 sq. in.
224. Discussion.
225. Discussion.
226. Weight of steam per hour = 910 lbs.
227. Weight of steam per hour = 5600 lbs.
228. Velocity of issuing jet = 1453 ft. per second.
229. Discussion.
230. Discussion.
231. (*a*) Air delivered = 388.2 lbs. per minute; (*b*) air delivered = 367.8 lbs. per minute.
232. Velocity of issuing jet = 2840 ft. per second; quality of steam issuing = 0.919.
233. Minimum superheat required = 205° F.
234. Minimum initial temperature = 582.5° F.
235. Per cent priming in steam = 2.6 per cent.
236. Maximum priming = 5.0 per cent.
237. Error (*a*) = 0.284 per cent; error (*b*) = 0.480 per cent.
238. Steam escaping per hour = 416 lbs.
239. Desired information cannot be obtained.
240. Impossible to determine quality by means of a throttling colorimeter.
241. Steam per horse-power per hour = 12.74 lbs.; velocity at throat = 1530 ft. per second; velocity at exit = 3780 ft. per second; diameter at throat = 0.308 in.; diameter at exit = 1.554 ins.
242. Entrance angle = 38°45′; velocity of blade = 1941 ft. per second; per cent of energy of jet utilized = 96.5 per cent; end thrust per pound of steam passing per second = 18.2 lbs.
243. Entrance angle = 36°2′; exit angle = 36°2′; velocity of blades = 1777 ft. per second; per cent of energy of jet utilized = 88.3 per cent.
244. Diameter of throat = 0.25 in.; diameter at exit = 1.281 ins.
245. Discussion.
246. Discussion.
247. Discussion.
248. Description.
249. Discussion.
250. Diameter at throat = 0.133 in.; diameter at exit = 1.441 ins.
251. Discussion.
252. Discussion.
253. Increase in entropy per pound = 0.0162 unit; loss due to throttling = 9.5 B.t.u. per lb.
254. Throat diameter = 0.213 in.
255. One minute, 7.44 seconds.
256. Five hours, 24 minutes, 3.6 seconds.
257. Fourteen minutes, 16.7 seconds.

AIR AND INTERNAL COMBUSTION ENGINES

290. Description.

291. Efficiency = 40.3 per cent.

292. Heat consumption per H.P. per hour = 18,850 B.t.u.; cylinder efficiency = 33.86 per cent.

293. Mean effective pressure = 79 lbs. per sq. in.

294. Temperature = 1150° F.; pressure = 428 lbs. per sq. in. absolute.

295. Proof.

296. Plot.

297. Higher and lower calorific values of gas in B.t.u. per cubic foot are (1) as supplied, 619.0 and 559.5; (2) under standard condition, 672.3 and 593.8.

298. Discussion.

299. Discussion.

300. Discussion.

301. Discussion.

302. Temperature at point A = 1300° F.; at atmospheric pressure = 1000° F.

303. 80.96 lbs. per sq. in.

304. 0.498; discussion.

305. Discussion.

306. Discussion.

307. Thermal efficiency = 7.54 per cent.

308. Discussion.

THE STEAM ENGINE AND THE RANKINE CYCLE

340. Steam consumption = 7.74 lbs. per H.P. per hour; thermal efficiency = 29.6 per cent.

341. B.t.u. consumption per H.P. per minute = 344; cylinder efficiency = 66.6 per cent.

342. B.t.u. per H.P. per minute: indicated 275.0, Rankine 152.8; pounds steam per H.P. per hour: indicated 14.77, Rankine 8.203; relative efficiency (cylinder efficiency) = 55.6 per cent.

343. Thermal efficiency = 19.2 per cent; B.t.u. consumption per H.P. per minute = 222 B.t.u.

344. B.t.u. consumption per H.P. per minute = 345; cylinder efficiency = 61.7 per cent.

345. B.t.u. consumption per H.P. per minute = 289.4; thermal efficiency = 14.65 per cent.

346. Steam consumption = 21.4 lbs. per H.P. per hour; thermal efficiency = 10.98 per cent; Rankine efficiency = 23.6 per cent.

347. Actual efficiency = 14.4 per cent; Rankine efficiency = 27.2 per cent; cylinder efficiency = 53 per cent; actual steam consumption = 15.98 lbs. per H.P. per hour; ideal steam consumption = 8.48 lbs. per H.P. per hour.

348. Boiler efficiency = 71.5 per cent; plant efficiency = 10.2 per cent; engine efficiency = 23.7 per cent.

349. Diameter of cylinder = 23.1 ins.; stroke = 46.2 ins.; revolutions per minute = 64.9.

350. Discussion.

351. Discussion.

352. Net heat transferred between A and B = 43.1 B.t.u.

353. (*a*) and (*b*) description and discussion.

354. Probable H.P. = 345.7.

355. I.H.P. = 290.

356. Cylinder efficiency = 57.7 per cent; heat lost per H.P. per minute = 108.3 B.t.u.

357. Discussion.

358. Discussion.

359. Discussion.

360. Discussion.

361. Discussion.

362. Discussion.

363. Discussion.

364. Efficiencies: Rankine, 24.29 per cent; actual, 13.05 per cent; cylinder, 53.7 per cent.

365. Weight of steam at A = .00601 lb.

366. Qualities: A, .555; B, .704. Increase in internal energy between A and B = 11.6 B.t.u.; external work = 4.19 B.t.u. Net heat received from the walls = 15.8 B.t.u.

367. Probable H.P. = 1890; cut-off in intermediate = 25 per cent of stroke; cut-off in low = 32 per cent of stroke.

368. Discussion.

STEAM BOILERS AND AUXILIARIES

390. Discussion.

391. Discussion.

392. Sketch and description.

393. Thermal units per hour = 33,450.

394. Thermal efficiency of plant = 17.3 per cent.

395. Probable error = 8 per cent.

396. Equivalent evaporation per pound of coal = 9.14 lbs.; error of test = 0.3 per cent.

397. Steam pipe 13 ins. diameter; safety valve 3½ ins. diameter.

398. Discussion.

399. Coal needed per hour = 310 lbs.

400. Discussion.

401. Area at entrance = 0.178 sq. ft.; area at exit = 0.250 sq. ft.

402. Cooling water needed per pound of steam = 38 lbs.; pressure in condenser = 0.84 lb. per sq. in.

403. Heat lost = 1,466,720 B.t.u.

404. Boiler efficiency = 57.6 per cent. Equivalent evaporation from and at 212° F. = 8.49 lbs.; boiler H.P. = 1232; grate area = 333 sq. ft.; flue area = 33.5 sq. ft.; heating surface = 12,320 sq. ft.

405. Water evaporated per hour by battery = 24,400 lbs.; combined boiler H.P. = 818; coal consumption per day of 24 hours = 69,200 lbs.

406. Coal burned per hour = 34.1 lbs.; grate area = 28.4 sq. ft.; heating surface = 1050 sq. ft.; flue area = 4 sq. ft.; air required per hour = 3580 lbs.

407. Quality of steam = 21.1° F. superheat.

408. Sketch.

409. Discussion.

410. Air per pound carbon = 20.3 lbs.; velocity of gases in flue = 409 ft. per min.

411. Heat lost = 1,306,000 B.t.u.

412. Thermal efficiency of boiler = 71.6 per cent.

413. Sketch and discussion.

414. Discussion.

415. Air per pound coal = 9.93 lbs.; oxygen per pound coal = 2.28 lbs.; gross B.t.u. = 13,019; net B.t.u. = 12,714.

416. Safety valve needed = 2 in. diameter.

417. Varies with rate of evaporation.

418. Thermal efficiency of superheater = 59.9 per cent.

419. 74.4 per cent.

COMPRESSED AIR

450. Work required = 55,000 foot-pounds.

451. H.P. required at compression cylinder = 169.1.

452. I.H.P. of compression cylinder = 26.4; I.H.P. of steam cylinder = 31.0.

453. Pressure in intercooler = 65.7 lbs. per sq. in.; I.H.P. of air cylinder = 241.5; I.H.P. of steam cylinder = 268.0; I.H.P. for isothermal compression = 192.

454. 16.14 H.P.; 80.75 per cent.

455. Time required = 140 minutes.

456. Work done per pound of air = 39,500 foot-pounds; depth of submergence required = 115.2 ft.

457. Sketch and discussion.

458. 142,000 foot-pounds.

REFRIGERATION AND HEATING

480. Description.

481. Maximum temperature, 361.8° F.; minimum temperature, 150.0° F.; work per pound air, 22,500 foot-pounds.

482. Refrigeration per pound NH_3 (1) 368.8 B.t.u., (2) 348.3 B.t.u.; coefficient of performance (1) 2.678, (2) 2.530; sketch and description.

483. 72,500 sq. ft. of heating surface; 600 boiler H.P.; 25 tons of coal per 24-hour day.

484. Drop in pressure = 2.63 lbs. per sq. in.

485. Loss from uncovered pipe = 3.55 boiler H.P.; loss from covered pipe = 0.47 boiler H.P.

486. Refrigeration per pound (NH_3) 436.5 B.t.u., (SO_2) 141.5 B.t.u.; coefficient of performance (NH_3) 4.878, (SO_2) 4.813; volume per 100 B.t.u. refrigeration (NH_3) 4.011 cu. ft., (SO_2) 10.80 cu. ft.

487. Power required by compressor cylinder = 68.7 H.P.; diameter of compressor cylinder = 16.6 ins.; liquid ammonia circulated per minute = 24.1 lbs.; power required at steam cylinder = 88.3 H.P.; diameter of steam cylinder = 12.0 ins.

488. Refrigeration per pound (NH_3) 502 B.t.u., (SO_2) 161 B.t.u.; efficiency (NH_3) 4.365, (SO_2) 4.351; volume gas per 1000 B.t.u. refrigeration (NH_3) 39.25 cu. ft., (SO_2) 105.6 cu. ft.

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